50 Manufacturing, Plant, and Production Management: Applied in Automobile Industry

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INTRODUCTION

The automobile industry uses automation and process control extensively. Application of modern automation techniques yields advantages to many manufacturers in diverse businesses for capturing greater market share compared to their competitors. In this chapter, automobile manufacturing methods, plants, production, and economics will be explained in detail.

The automobile sector is a key industry in a number of economies around the world. The European Union is the largest automotive production region (34%) producing the largest number of automobiles in the world. The industry makes up 7.5% of the total income of the manufacturing sector in the European Union. Direct employment by the automotive industry equals over 2 million employees. Due to the complex network of suppliers and other cooperating companies, the total employment effect is known to benefit about 10 million people, as estimated by the European Commission. In July 2009 according to European Automobile Manufacturers Association (ACEA), the industry operates 296 vehicle assembly and engine production plants in Europe. This number is including the EU27 and a number of neighboring countries, such as Russia, Ukraine, and Turkey producing passenger cars, light commercial vehicles or vans, buses and coaches, and medium-sized and heavy duty trucks and engines. The overview of vehicle production across the world is presented in Figure 50.1.

Nowadays the automobile manufacturing is moving to the East. Russia, India, and China are forecasted to be favorite locations for automobile production plants in the coming years, because of lower production costs, presence of growing demands in those regions, and large sales potential. In 2009, China has become the biggest automobile sales market with government stimulus helping to sell 11–12 million new automobiles in a year, according to the National Development and Reform Commission of China.

The automobile sector is highly consolidated. The annual global overcapacity of about 30% has even grown higher last year, which has led to price wars for market share among the manufacturers. The year 2009 was the worst in decades for all the automobile manufacturers. In Europe, for example, the drop of vehicle production in 2009 was on the average 26% compared to the previous year. The global downturn in sales has forced automobile makers to review their structures and processes. In order to maintain their weakened position due to crises, the automobile makers have to operate their production sites even more efficiently and adapt more flexible, timely, and customer-oriented approaches in their production lines.

ORGANIZATIONAL CONDITION IN AUTOMOBILE INDUSTRY

The automobile plants started to grow in early twentieth century. Introduced in 1903 by Henry Ford, high-volume mass production model had become a standard for automobile plant's organization for many decades, especially in North America and Europe. The Ford system is based on the workflow and the raw materials that are machined and carried along conveyor belts to be transformed into assembled parts. The various components are then supplied to each of the final assembly processes with assembly line itself moving at fixed speed [1]. The mass production model is characterized by

- Large lot sizes
- Stationary assembly
- High specialization of tooling and workforce
- Production process divided into a big number of narrow specialized operations
- Fixed speed of assembly operations
- High utilization rate of machinery (high capacity usage)
- High level of reworks
- Parts/components mainly manufactured in-house
- Low flexibility of production

At the opposite of the mass production approach is *lean* manufacturing. Lean manufacturing is a philosophy of production that emphasizes on the minimization of the amount of all resources used in the various activities of the enterprise (APICS Dictionary, p. 71). It involves identification and elimination of nonvalue-adding activities from the design level through supplies management up to the production and distribution levels.

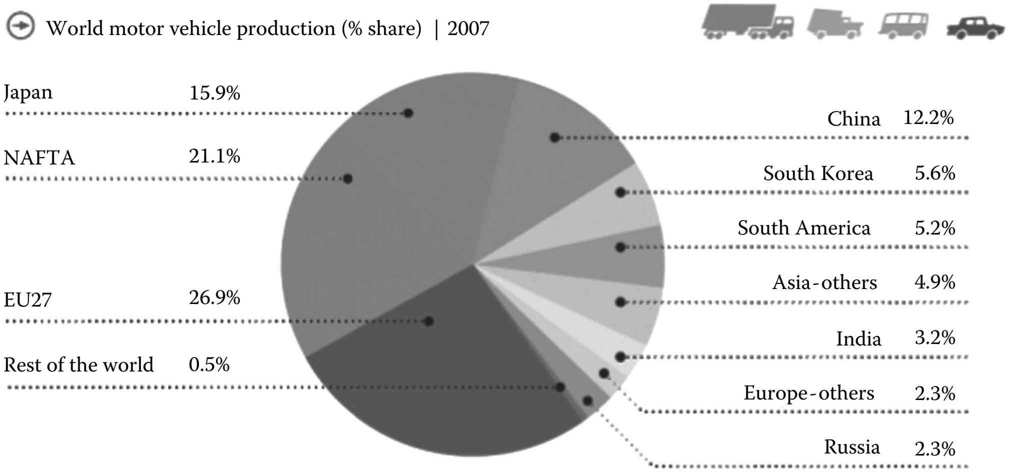

FIG. 50.1
World vehicle production. (From www.acea.be)

The main representatives of lean production systems are the Japanese automobile manufacturers. The precursor of this production system was Toyota, whose chief executive Taiichi Ohno [1] has described the Toyota production system (TPS) with its core elements as *kaizen* (continuous improvements), *muda* (waste reduction), and *kanban* (inventory reduction). Kaizen enhances the quality of products and processes. Due to the continuous and systematic approach, it highlights problems and pinpoints their root causes and eliminates them through the application of rigorous methods of operations. TPS system works on the premise of eliminating overproduction generated by inventory. Kanban system helps to reduce the number of units in the inventory in-house. In kanban system, a later process goes to an earlier process to withdraw parts needed just in time. In order to reach this goal, the earlier process produces only as many parts/components as are needed to be picked up by the successive process. The workers and equipments at each section of the production process should have enough capacity to produce the number of parts/components required even in demand-fluctuating situations. This system was named “lean production” by Womack, Jones, and Roos of MIT in their study “The second revolution in the automotive industry” [2]. In production, lean means concentration on value-creating processes and high quality in vehicle assembly. The main characteristics of lean production are

- Small lots (one item per lot)
- Quick set up times
- Very strict quality standards
- Multiskilled workers
- Flexible automated machines
- Elimination of overproduction
- Lower utilization of machinery (overcapacities)
- High level of parts/components manufacturing outsourcing
- High flexibility of production

In lean manufacturing, emphasis is placed on the complex and systematical elimination of waste. The downturn of automobile sector with plant shutdowns and shortened workweeks has caused a renaissance of the lean approach. There are two lean management techniques: *kaikaku* and kaizen. Kaizen highlights steady and incremental improvements, so it works best for relatively stable and mature organizations. Kaikaku, in turn, represents radical improvement and fundamental change [3], so it is more suitable for companies that face extraordinary challenges such as takeovers or turnarounds.

In the first step, kaikaku starts with a review of all processes, and it questions the need for their existence and their potential for value creation from the customer’s perspective. Processes that do not create added value for the customer are scrapped. For example, production quality audits often are eliminated because they frequently consume a disproportionate amount of time and resources, delaying production. Quality should be not obtained by rigorous quality control and following them with reworks/refinishing but by a high quality of design and processes. It is better to substitute quality control with proper investments in overall quality-enhancing tooling, competencies of the workforce, or upgraded processing techniques. The efficiency gap between Europe and U.S. automobile plants compared to the Japanese automobile manufacturers is caused mainly by high level of refinishing operations (sometimes even up to 40%–60% of production). In a second step, kaikaku reviews all value-adding processes in order to eliminate any duplication of work and obvious inconsistencies. This step should be combined with sufficient definition of standards, roles, and responsibilities in order

TABLE 50.1

Typical Implementation of Kaikuku

	Initial Situation	*Results (After 6 Months)*	*Effects (%)*
Process times employees	2470 h	1510 h	−39
Footprint	2011 m^2	634 m^2	−68
Inventories (work in process)	4600 units	700 units	−85
Lead time	35 days	9 days	−74
Hourly output	27	125	+363

Source: Dinkel, H. and Birchler, B., *Autom. Manager*, 1, 18, 2009.

to avoid duplication of work. In the third step, the causes of waste are identified and eliminated. Then the company is able to standardize processes and introduce appropriate key figures down to the operational level. Step four of the kaikaku program aims to integrate the entire organization in order to transfer the necessary expertise to customers. The final step requires commitment of all employees to firmly anchor the obtained results of this radical improvement within the organization. Moreover, kaikaku should be followed by kaizen. Kaikaku can help an automaker fundamentally rebuild its organizational structures in a short period of time while simultaneously creating the foundation for significantly higher efficiency [3]. The results of kaikuku project implemented by Oliver Wyman in one of automobile plants are presented in Table 50.1.

After mass production and lean production, the global automotive industry is facing another structural evolution, namely collaborative engineering and production. The automobile manufacturers have redefined their core activities and a growing importance of outsourcing can be observed. Outsourcing is understood here as a process of having suppliers provide goods and services that used to be traditionally performed in-house. Suppliers are increasingly involved not only in deliveries of particular parts but also in R&D, preassembly, and market research. A Mercer Management Consulting study based on industry interviews, data analysis, and economic modeling concludes that by 2015, automotive suppliers will perform close up to 80% of total value creation in light vehicle engineering and production, as the automakers restrict their own share to those components and activities that are crucial to the success of their brands [4]. Figure 50.2 presents the changes in value creation by assembly of main automobile modules/systems.

The production process in the automobile plant can be divided into three main phases, namely, establishment of car body, painting at paint shop, and final assembly. An example of production process model is given in Figure 50.3.

In most of the cases, especially for European manufacturers, the production system is characterized by high stability that is understood as [5]

- Steady production plans per day/week
- Master production schedule (MPS) prepared many weeks in advance
- High similarity of production routines
- High similarity of product structure, however they may differ in number of specific attributes like, for example, color

In order to better understand the processes in the automobile plant, the following assembly variants need to be introduced:

- Semiknocked-down (SKD) systems: The workers assemble the vehicles by mounting the engines, arbor supports, driving unit, and other smaller parts into an already painted body. Then they evaluate the assembled car on the mount rack for dynamic property testing, inside the light tunnel, and run the car on the proving ground located on the plant territory.
- Medium-knocked-down (MKD): The manufacturing process starts with painting operations of already welded car body shell. In the next manufacturing phase, the engine, transmission, arbor support, electric systems, driving systems, cockpit furnishing (interior plastics), and other smaller parts are mounted into the car body.
- Complete-knock-down (CKD): This is the most complicated variant of assembly operations. The automobile is built up from small parts starting with welding operations at the body shop, anticorrosive coating, painting, and preassembly of some systems, for example, engine, gears, and cockpits. Then all the parts, systems, and modules are mounted into car body.

The final assembly of almost all cars is organized in "zero inventories" mode. The zero inventories model by assembly operations is characterized by

- Unification and standardization of used parts, components, and module.
- Pull system.
- Introduction of fixed structure of final assembly schedule that helps to reduce planning tasks complexity (planning activities are described in detail in next section).
- Setup time reduction: the setup time is understood as a elapsed downtime between the last piece production of part X and the first good time production of

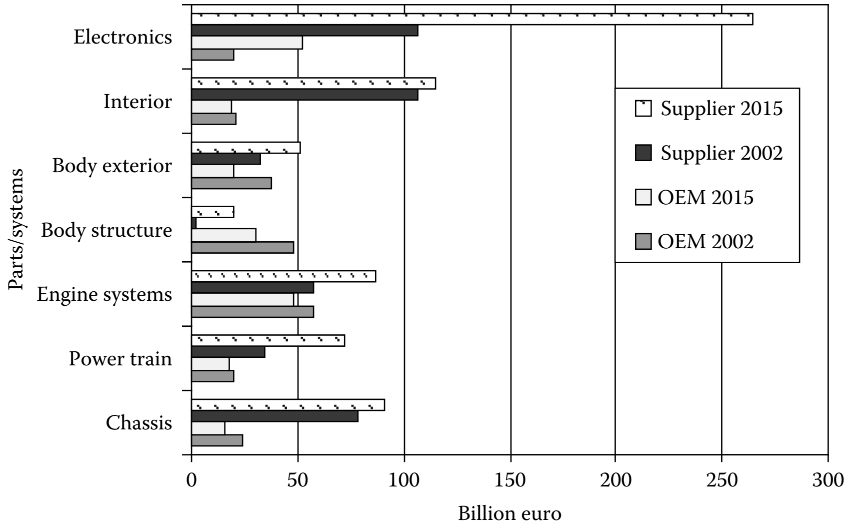

FIG. 50.2
OEM value creation. (Elaborated based on data from Kleinhans, C. and Dannenberg, J., Mercer Manage. J., 17, 88, 2004.)

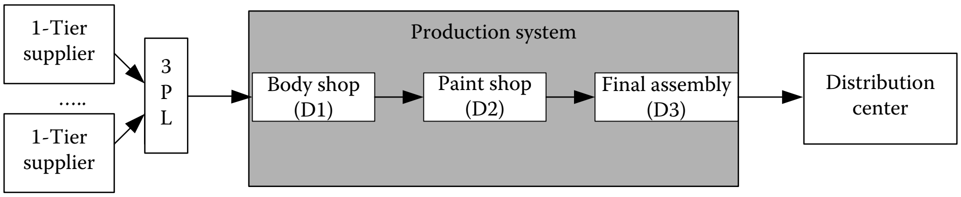

FIG. 50.3
Example of production process model with a CKD system.

part Y. In a number of companies, it is assumed that setup time should be less than 10 min. When this goal cannot be reached directly at the work station, some presetup activities are accomplished outside the work station by so-called external setups.

The typical processes in automobile plant can be divided into

- Production planning activities
- Procurement and suppliers network management
- Production control and disturbances management
- Reverse logistics and remanufacturing

PRODUCTION PLANNING

In order to protect the stability of their production system and to gain economy of scale, the manufacturers combine two policies in production planning, as follows:

- Build-to-forecast: According to some average company standards, customers are served from inventories of final goods.
- Build-to-order: A demand-driven production approach that aims to provide vehicles built according to specification of individual clients in a minimal lead time.

The automobile manufacturers apply very often “late-fit strategy.” It is an upgraded version of build-to-forecast strategy, whereby forecast orders in the pipeline are amended to customer requirements at the assembly line.

Due to the fact that Europe is still the biggest automobile manufacturing region in the world, the planning process is discussed on the basis of business practice applied in this region. As studies conducted in the framework of “3DayCar” program [6] had showed, a forecast of customers’ demand regarding volume and item specification is prepared many months in advance. This approach helps to figure out an attractive product mix for assembly plant balancing. Actual customer orders that are received are either fitted into the plan laid out months ahead, or the forecast orders in the system are amended to particular customer’s requirements. On the average, in Europe, an order-to-delivery lead time is 40–60 days for custom-built vehicles. European automotive industry production scheduling is prepared 2–3 weeks before production starts. Order scheduling, which are picked from the order bank, are assigned to production weeks at different plants. The scheduled orders for a production week are reshuffled into a sequence of build orders for the assembly plants. Only after the orders are sequenced, the suppliers actually receive their final call-off of what is required, as only then it is actually defined what parts will be needed [7]. Sequenced orders are sent to the body shop (welding department).

The paint shop is the most typical bottleneck of the production process. In order to achieve efficiency of this bottleneck at the paint shop, bodies to be sprayed in the same color are grouped together. The initial production sequence is distorted and becomes unpredictable for all subsequent operations. After paint, the cars are generally reshuffled again before they are sent to the assembly department in order to ensure the mix of cars needed for the line balancing activities. Due to the high fixed cost of production system, the automobile industry is focused more on the efficiency/capacity utilization performance in the assembly plant and the volume of sales in the market, and often fails to deliver specific customer-ordered vehicles within a satisfactory timeframe. Moreover, the large levels of stocks of finished automobile are typical in the automobile industry. There is a kind of a vicious cycle in automobile plants. On one hand, manufacturers are aiming to gain the profits of economy of scale assured by built-to-forecast approach. On the other hand, this approach causes extensive stock levels and oftentimes requires a discounting policy in order to clear the stock. Demand-driven approach (built-to-order) does not provide full utilization of capacities due to distorted market information, and this results in lower margins and profitability. Figure 50.4 presents the order-to-delivery process in an automobile plant.

The order-to-delivery process is modified [7] as

1. *Order entry*, which is a check whether the orders are feasible to be built, and if they are, transfers them into the order bank.
2. *Order bank*, which holds all unsold orders until they are scheduled for production. The order bank does not fulfill any real purpose apart from providing a comfortable buffer for the manufacturer to achieve efficient production.
3. *Order scheduling*, which picks the orders from the order bank and assigns them to build periods (generally weeks) at the different plants. The scheduling tool takes parts availability, market, and dealer fair share allocations and mix constraints into account, most of which are decided in the production programming meeting.
4. *Order sequencing*, where the scheduled orders for a build week are reshuffled into a sequence of build orders for the assembly plants. The sequencing tool needs to take build constraints into account. In any case, only after the orders are sequenced do suppliers actually receive their final call-off of what is required, as only then it is actually defined what parts will be needed. This is another reason why holding scheduled orders is of very limited use and explains why the schedules issued by the manufacturers show a high degree of fluctuation.
5. *Manufacturing*: Once sequenced, orders are sent to the body shop, where the order is generally identified with the physical floor pan, which then becomes a complete body. After the body shop, the body enters the body-in-white storage; the only purpose is to achieve efficiency in the paint shop by grouping bodies that are

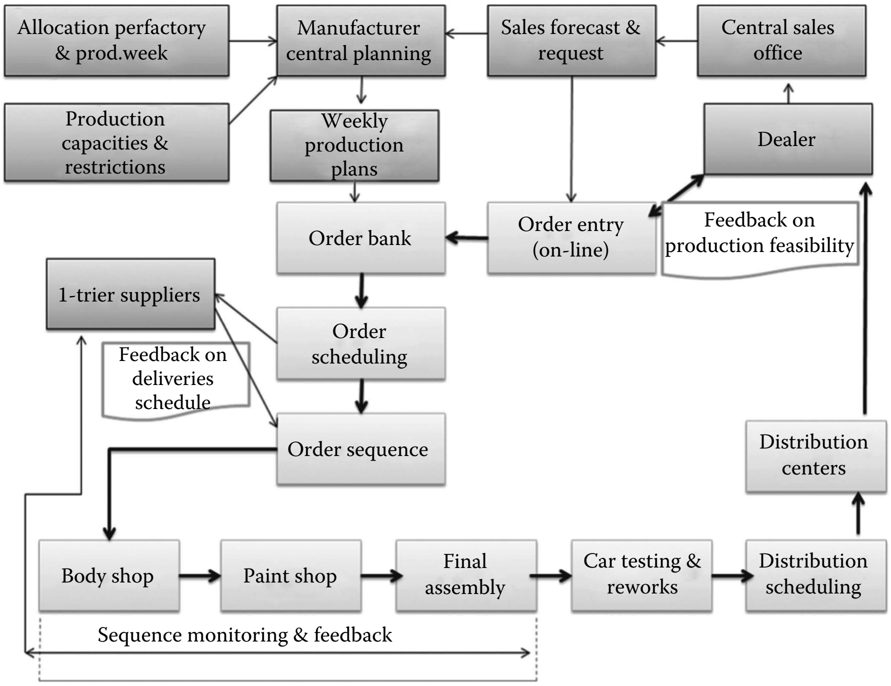

FIG. 50.4
Order-to-deliver process. (From Holweg, M. and Jones, D.T., The challenge of building cars to order, can current automotive supply chains cope?, http://www.3dayscar.com, 2000.)

> meant to be sprayed in the same color. The downturn of batching is that the initial production sequence is distorted; hence it becomes unpredictable for all subsequent operations as to what cars are coming down the process. After paint, the cars are generally reshuffled again before they are sent on the assembly track to ensure that a mix of cars are aligned with the constraints of by the line balancing activities.

It is estimated that over 80% of delays in the order fulfillment process are caused by configuration of premanufacturing activities, like configuration of bank orders, order scheduling, and order sequencing.

The typical planning processes in automobile plant can be summarized as in the Table 50.2.

Planning is the process of selecting and sequencing activities in such a way that they satisfy the customers' demand taking into consideration the set of automobile plant's internal constraints. Scheduling can be defined as a process of selecting among alternative plans and assigning resources in the particular time framework to a set of activities in the plan. Schedules should reflect the temporal relationships between activities and the capacity limitations of the set of shared resources.

Prospective production plans are very often prepared in a centralized manner. They cover sales forecast for a particular region, as well as take into consideration rough capacities of a particular brand of the automobile plants in the region. The centralized prospective plans are than assigned for plants' subplans.

MPS is the most important planning and control schedule in business due the fact that it states what kind of end products should be produced and helps primarily verify whether customers' orders can be fulfilled on the due-to-deliver date. It is a main driver and information source for further material requirement planning and accompanying calls for supplies. It allows making detailed final assembly schedules for production system resources like manpower, machines, and internal transportation in the planning horizon. MPS helps allocating production as a summary in daily buckets. Then replanning is made at least once a month but manufacturers try to update the MPS schedules more often. The preferred frequency of replanning is 3–4 weeks. Usually 2 weeks before the production starts, the MPS is frozen (no incremental changes are allowed). This business practice helps to secure the on-time deliveries of components and parts. The planner might need to revise the MPS if feedback from production departments highlights some problems like bottleneck or shortages of workforce. As a rule, the frequency of MPS replanning should be reduced to a minimum.

The final assembly schedule (FAS) is prepared on the basis of MPS usually 2–3 weeks before the production due date. It shows in detail production sequence for every day (per production shifts). The FAS depends on the company's capacity constraints (e.g., a maximum of 50 automobiles with automatic gear per shift, at least 4 automobiles in the same color per block, etc.) and availability of materials. These schedules are also sent to suppliers and discussed with them. The FAS is supposed to be executed at the unit level but due to the disturbances, almost every shift appears to have some variations.

Material delivery plans result from the accepted FAS. They point quantities, delivery due dates as well as exact production sequence if applicable. The procurement process is explained in detail in the next section. Figure 50.5 presents the example of FAS elaboration by one of the European automobile manufacturers.

Procurement and Suppliers: Network Configuration

The automobile industry's competitive edge is placed on a continuous price reduction combined with high quality expected by the customers. Production costs are increasing because of the proliferation of models and furnishing options. Cars are becoming more complicated, so there is a struggle

TABLE 50.2

Typical Planning Process of an Automobile Plant

Hierarchy	*Time*	*Data Required*	*Output*
Strategic production plans	Up to 5 years	Capacity data, investments plans, manpower, long term sale forecasts, long term market search, R&D plans	Call for investments, Company's employment forecasts
Prospective production schedule (PS)	Covers 12 months (updated every 3–6 months)	Sales forecast/plans, placed orders, rough production capacity	Monthly rate of each model (production in monthly bucket)
Master production schedule (MPS)	Covers 1–6 months (typically updated week $n-3$ or $n-4$ before production starts in week n)	Prospective production plan, updated forecast, actual orders	Production of each model in week bucket including specific configuration, quantities, dates
Final assembly schedule (FAS)	Covers one week (daily orders assignment)	MPS Company constrains, suppliers constrains	Sequence of automobiles to be assembled every day/every shifts
Materials delivery plan (or materials requirements plan)	The same as final assembly schedule	MPS, Final assembly schedule, bill of material, delivery lead times, supplementary suppliers' data	Calls for suppliers, delivery quantities, sequence or cycles

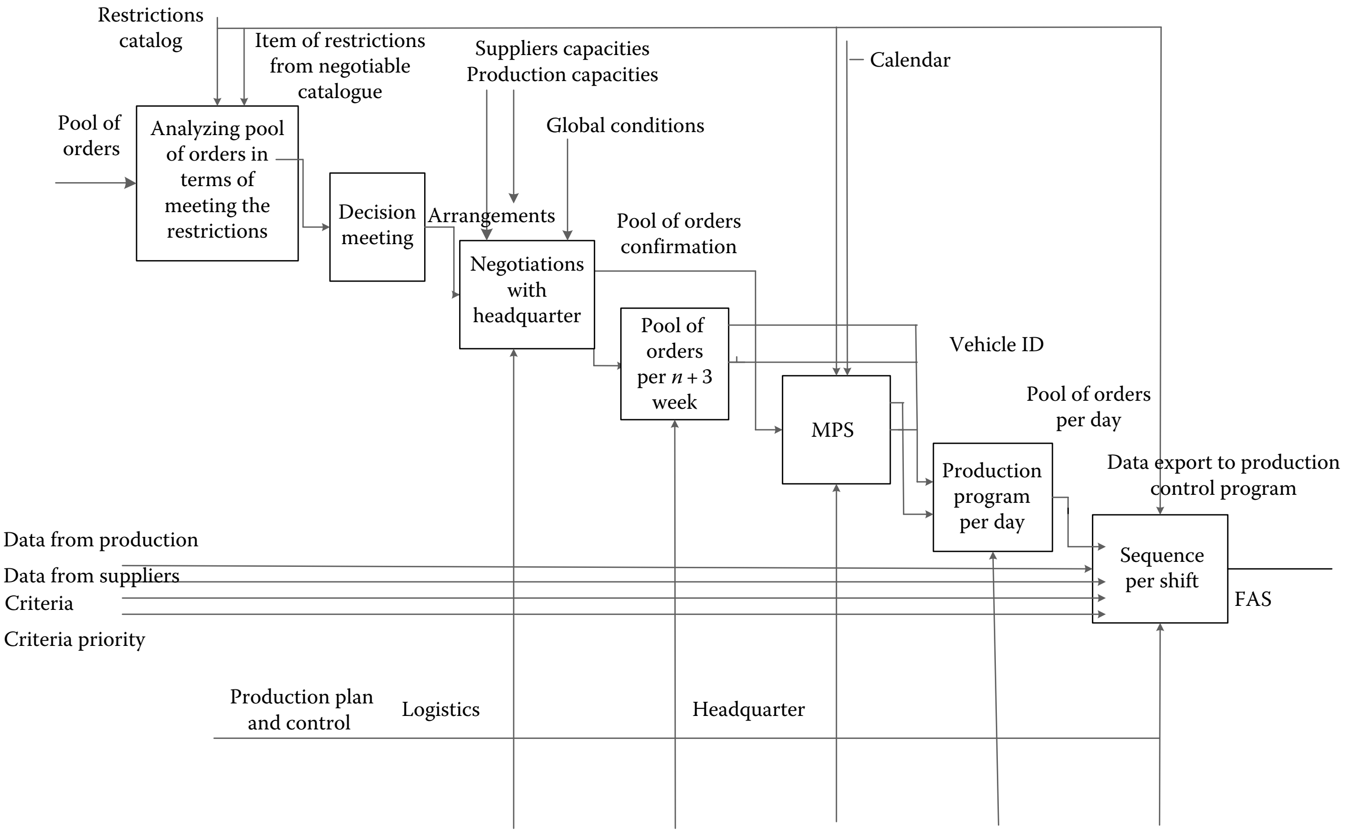
Restrictions catalog
Item of restrictions from negotiable catalogue
Suppliers capacities
Production capacities
Calendar
Pool of orders
Analyzing pool of orders in terms of meeting the restrictions
Global conditions
Decision meeting
Arrangements
Negotiations with headquarter
Pool of orders confirmation
Pool of orders per n + 3 week
Vehicle ID
MPS
Pool of orders per day
Production program per day
Data export to production control program
Data from production
Data from suppliers
Criteria
Criteria priority
Sequence per shift
FAS
Production plan and control
Logistics
Headquarter

FIG. 50.5
FAS elaboration process source.

between growing number of vehicle systems and declining number of parts per system/module.

The automobile industry moves from make-to-stock to assembly-to-order approach. The original equipment manufacturers (OEMs) have to react quickly to fulfill the customer demand and at the same time have to be technically innovative. The high cost pressure for the OEMs creates a need for them to work together with their suppliers. The automobile industry has one of the most complex supply chains among all the industries. The upstream of material pipeline includes hundreds of parts and component suppliers, and the downstream part cumulates thousands of car dealers and repair shops. The supplier network is a hierarchy with close relations between the automobile assembler and suppliers. A low amount of suppliers, the pyramid hierarchy, and the prenegotiated contract conditions reduce the competition inside the supply system and focus shifts to the end product and therefore on the car manufacturers themselves [8]. The trend of strategic outsourcing has a sustainable impact on the value creation in the automotive industry.

For over a decade, outsourcing in automobile industry was a necessity, resulting in a fraction of components obtained from in-house supplies declining every year. In Europe, outsourcing is still increasing, while in America, due to the recent financial crisis, assemblers try nowadays to move some part of manufacturing in-house. In Europe, OEMs are outsourcing an increasing number of noncore processes. Shifting more component responsibility to supply chain partners allows OEMs to be closer to the market and become less vulnerable to demand fluctuations by lower investments in fixed assets (e.g., machinery and tooling). In the United States, insourcing trend is very strong since 2009, due to the strong workers union and extensive overcapacities. Companies have started bringing production of components like dash boards or cockpits inbound. This approach allows to secure jobs that would have been lost. This trend is too short lasting to evaluate its long-term impact on other automobile manufacturer markets. Despite the U.S. inbounding trend, the traditional division into *n*-tier suppliers is still applicable as discussed in the next section.

The advantage of outsourcing is (beside lower costs) also improvement of quality due to the access to new technologies and innovative components. Top suppliers deliver their components usually to a number of different car brands. Due to the economy of scale resulting in lower production cost per unit, they are able to invest more in R&D. Their patents are usually implemented in several products of different car brands, which is advantageous compared to a situation where every car company had to develop their own technologies (Exhibit 50.1). Due to lower cost, more and more engineering and production work is moved upstream to the

EXHIBIT 50.1

Robert Bosch GmbH is the world's largest automotive supplier. It supplies several of the 13 major automotive OEM companies with high-tech and high quality components and subsystems like braking system, traction control system, starter motors, and generators.

Robert Bosch GmbH invested €3583 million in R&D in 2007 and €3889 million in 2008, which corresponds, respectively, to a 7.7% and 8.6% share of its total revenue. In comparison, well-known innovative car companies like Toyota achieved an R&D ratio of 3.7% share of its total revenue and BMW 5.2% in 2007. Bosch developed 3280 patents worldwide in 2007 and filed 3850 patent applications in 2008.

Despite the fact that the global automobile production collapsed in every part of the world at the end of 2008, the sustained trend toward more eco-friendly vehicles was growing. This results in the race for making cars of the future cleaner, safer, and more economical. To make this "invented for life" technology available in the market, Bosch GmbH has increased R&D expenditure once again last year to the equivalent of roughly 12% of revenues in automotive technology. (*Source*: Elaborated based on data from www.bosch.com)

suppliers. They can concentrate more on development and production of particular components/modules than OEMs. Both the OEM and the suppliers focus on the processes they have the best competencies in, which leads to a comparative advantage. The focus on core competencies leads to better brand image and quality of automobile, as well as to a decrease of deficiencies and a direct reduction of mainly variable costs.

Offshoring is a standard approach in the automobile industry. Latin America, Asia, and Eastern Europe offer dynamic low-cost models. These regions are a privileged destination for a number of automotive manufacturers, which locate their assembly plants in these regions usually connected with component production sites. Cost reduction potential according to MGI Wage Watson Wyatt survey are as presented in Figure 50.6 (reprinted from "Right-shoring," a white paper of Exel company, www.exel.com).

The abovementioned tendencies, which are observed in procurement process in the automobile industry, can be summarized as

- Limitations of supplier number
- Shorter product life cycles
- New models show up quicker (24 months)
- Lower profit margins

Structure of Suppliers: Network and Management of Procurement

Typically, automobile plants group a large number of suppliers at the same location or in the vicinity. The concept of suppliers' network has spread from Japan automobile industry all over the world. The established hierarchy of OEMs and first and second tier suppliers is still the dominant form of collaboration. OEMs are more focused on the downstream business like sales, when at the same time, the upstream part of supply chain is coordinated by suppliers. Modularization is an important technique that allows better controlling the increasing complexity of cars. Most OEMs focus on high-tech components or corporate identity components (e.g., security for Volvo, comfort for Mercedes-Benz, reliability for Toyota), which give them a competitive advantage through brand management [4]. Nowadays there are over 4000 automotive supply companies with revenues of more than €20 million per year. The rationalization of supplier base is an important issue. OEMs try to reduce the number of direct suppliers. There are focal firms (so-called 1-tier suppliers) that integrate their own inbound network of suppliers (2-tier and *n*-tier) and are responsible for their performance. Suppliers are assessed based on the percentage of on-time deliveries in proper quantity and sequence, and also

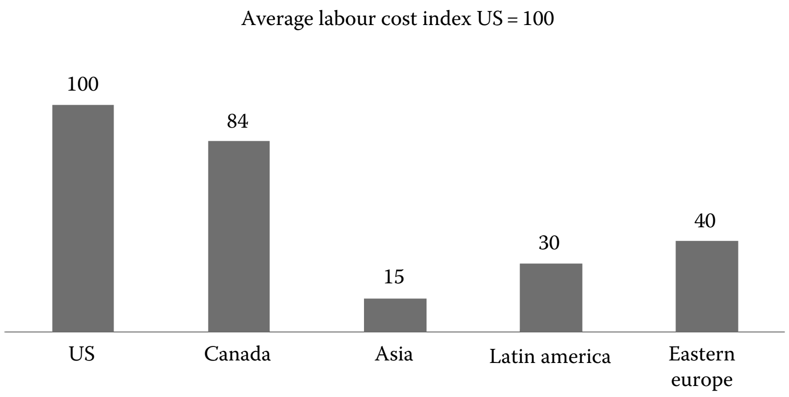

FIG. 50.6
Cost reduction potential by target country. (From www.excel.com)

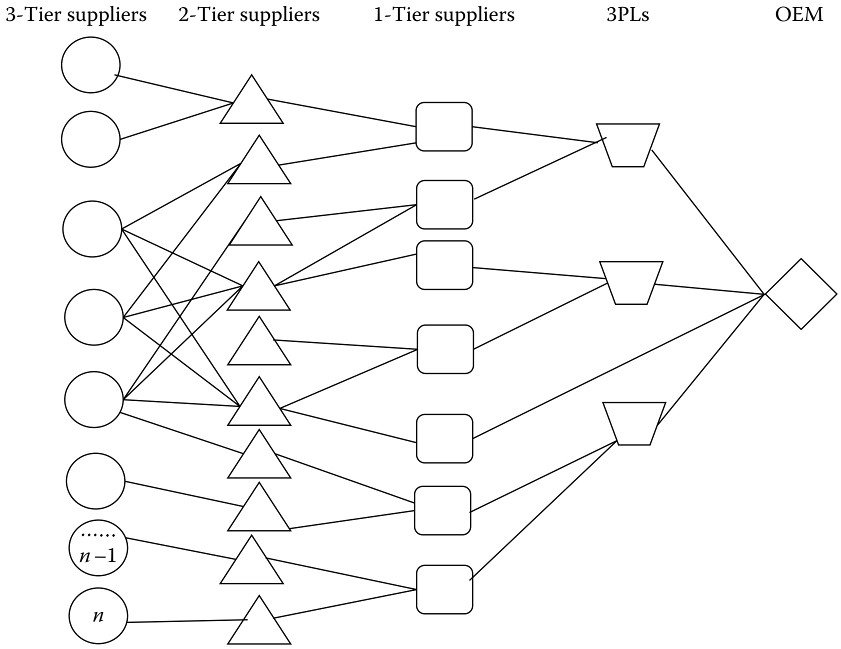

FIG. 50.7
Suppliers' hierarchy in automobile industry.

performance in reducing cost is crucial. Suppliers providing technologically advanced parts or complex modules/systems have a stronger bargaining power with the OEM. Figure 50.7 presents suppliers' hierarchy.

Depending on their competences, the lead suppliers can be divided into three categories [9]:

1. Traditional 1-tier supplier with in-house design capability who can assure timely delivery and required quality as well as safety stock. They meet the goal of quality consistency of 25 ppm (pieces per million), while tough price reduction is demanded.
2. 1-Tier synchronic supplier whose materials flows are synchronized with the assembler so that there is no safety stock kept. Parts are delivered just-in-sequence (JIS), with very limited stock (on-wheels inventory) of what is needed to transport parts from the supplier to the assembler. These suppliers are located in the manufacturer factory's neighborhood (usually within radius of 50 km). They are usually connected with the assembler through an IT infrastructure.
3. Tier 0.5 full-service providers, who integrates component manufacturing through supply chain management in order to reach the goal of optimum creation of a particular module. They play an important role in the cost-cutting process. As the partners in supply chain, they are responsible for shelf engineering and presale market research.

The 2-tier and the sequent tier suppliers compete mainly on prices, so their profit margin is low. Usually they are not able to provide innovative services, like the 1-tier suppliers. The quality standards are lower and the failure rate is on the average 1%–2% (1000–2000 ppm).

Also logistics service providers play an important role in the procurement process. The typical services performed in automobile plant by logistics providers are as follows:

- Holistic logistics strategies for just-in-time (JIT)/JIS supplies to module assembly lines and final assembly lines
- Milk run and hub-and-spoke parts supply systems
- Warehouse management
- Module preassembly
- JIS delivery to assembly lines

The characteristics of particular procurement systems are given in the next subsection.

Variants of Procurement Systems

Depending on the level of cooperation between assemblers and suppliers, the following types of procurement systems can be found in automobile plants:

- Direct deliveries to assembler warehouse
- Delivery via consolidation center to assembler
- Delivery to on-site distribution center
- Deliveries from suppliers' part in JIT mode
- Deliveries from suppliers' park in JIS mode
- Hybrid systems

Direct deliveries are usually provided by lead suppliers. In this procurement system, the supplier is responsible for delivery of parts directly to warehouse in assembler's factory. The suppliers carry out all cost connected to the freight and insurance charges.

Delivery to consolidation center or *order dispatch centers* [9] represent a centralized approach to procurement. The assembler subcontracts the process of parts collection from a number of suppliers who are visited at a predefined frequency. The parts are taken to a consolidation center where they are divided into trailers designated for different assembly plants. An example is the Hyundai, which subcontracts to Glovis Ltd. This logistics provider collects automobile parts made in the Asia region, packs them, and dispatches to Hyundai plants around the world in the so-called CKD system. All deliveries are monitored based on the radio frequency identification (RFID) global tracking system. Another example is Penske Company, which is Ford's lead logistics provider, explained in Exhibit 50.2.

EXHIBIT 50.2

Ford owns and produces automobiles under several major brands: Ford, Lincoln, Mercury, Mazda, Land Rover, Aston Martin, and Volvo. It maintains one of the automotive industry's most complex logistics systems. Suppliers have to make multiple deliveries of the same parts to different plants (up to 20 in North America). A supplier needs to pick up a small load, deliver it to one plant, and then pick up another small load of the same parts and deliver it to another plant. The usage of carriers load was low, due to half-empty trucks, which would often cross routes with each other en route to the same plant. This system was highly inefficient. In order to centralize transportation and distribution operations, Penske implemented a solution consisting of 10 new order dispatch centers (ODCs). Different supplier shipments going to the same plant are now cross-docked into trailers at the ODC. Loads are consolidated and delivered on a scheduled basis. This approach helps to optimize the transportation activities by reducing the number of milk-runs, less than truckload shipments (LTL) and premium freight charges. Moreover more than 1500 suppliers were trained in new procedures in order to meet Penske's new transportation and distribution standards. (*Source:* Elaborated based on data from www.GoPenske.com)

Delivery to on-site distribution center (DC): Parts from suppliers are delivered to the lead logistics partner (LLP) located closer to the assembler's factory. The advantage of such a delivery system is easier control of inbound parts movement into the plant. The assembler is able to better monitor flow of materials into the plant and reduce vehicle congestion (Figure 50.8).

Deliveries from suppliers' park in JIT mode are organized by schedules or signals. The suppliers are usually located in the neighborhood (maximum of 50–100 km) in so-called suppliers' park. 1-Tier suppliers are informed about qualitative and quantitative order requirements at three or four time points. The first approximate information on required components and materials is given to suppliers when sales plan is agreed usually 3–6 months before the production starts. The second call is given just after the MPS is agreed upon (3–4 weeks before beginning of production). The last call for supplies of components takes place 1–48 h before the need of delivery (e.g., when automobile leaves paint shop and enters assembly line). When using signals, the last call for suppliers is sent by application of kanban. The kanban uses standard containers or lot sizes with a single card attached to it. In this pull system, the team at the assembly line signals with a card that they need next delivery of a particular component. The supplier is usually connected with the assembler via the IT infrastructure.

There is no stock at assembly line and parts are delivered straight to the receiving point. The receiving point is rather place of collecting and inspecting than a dock. In some companies, the JIT supplies are delivered straight to the assembly line. Workers in the receiving side at the assembly line check the quantity and quality of incoming parts. Using the optical scans and bar codes from cards placed on each body shell, they update the data by a running part number. Sometimes summary cards are used in order to avoid handling a volume

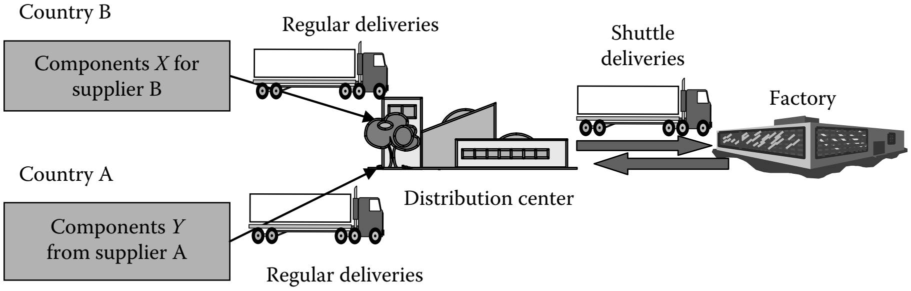

FIG. 50.8
Delivery to on-site distribution center.

of cards. Usually suppliers are paid for what they have delivered. The cards are used by suppliers as a pull signals for their deliveries. The standard and nonstandard containers are used depending on size and shape of the parts. The containers are placed directly next to assembly point (usually on the flow shelves). Every container is labeled with card containing assembly information, such as

- Part/component identification numbers
- Product description
- Number of parts per automobile
- Production date and hour of the latest shipment to the assembler

After container/part bar code scanning the order for next delivery is issued automatically by the assembler's IT system, it is sent to the supplier. The suppliers are responsible for quality assurance of the deliveries.

JIS from suppliers' park deliveries are a next generation of JIT deliveries. All the parts/components are delivered directly to the assembly point in the exact sequence. Each part is placed in the container in a particular sequence and signed with a vehicular identification number (VIN) of the automobile in which it is supposed to be mounted. Good examples of JIS deliveries are mirrors, which are prepainted before assembly, so yellow mirror goes to the exact yellow car, blue mirror to the blue car, etc. Figure 50.9 presents the JIS logic.

JIS deliveries require very good information synchronization between the assembler and the supplier. Any disturbances at the assembly line, which are causing variation in the production sequence, should be immediately notified to the suppliers. Otherwise materials needed for the particular order may not be available.

Hybrid solutions: Module synchronic delivery (from parts via subassemblies to modules) includes (Exhibit 50.3) involvement of the supplier's workers directly in the production process

EXHIBIT 50.3

According to Harbour Report, BMW plant in Leipzig is one of the most efficient in the world. The plant was built in very close collaboration with one of BMW's major supplier (Siemens). The automation grade is very high (97%). Several other suppliers like FFT, Edag, or Emil Bucher are involved in the welding lines production for assembling the underbody of the car [10]. The suppliers play a key role and are integrated in innovative way into the production itself. BMW built a supply center with direct links to the assembly hall. Suppliers preassemble their modules. The parts from the different suppliers are moved fully automatically JIS on the shortest route to the assembly line.

Three lead third-party logistics service providers (LLPs) are involved:

1. Rudolf logistics for body shop logistics
2. Schenker logistics for assembly
3. Infraserve handles non-series production logistics, including spare parts

Over 150 Schenker employees work next to the BMW workers on the same assembly line. They execute assembly operations in two module assembly areas where five different suppliers rent space and prepare modules JIS. Almost 80% of the daily material is supplied "just in time" or "just in sequence" by the logistic service providers [11].

The assembly is structured like a comb. Specially designed extensions to the buildings facilitate delivery of the over 10,000 m^3 of material used in production every day. Most of materials are delivered with lorries to all places of assembly. The design of assembly is very flexible, allowing extension of additional assembly operation in the future. Figure 50.10 presents the facility layout.

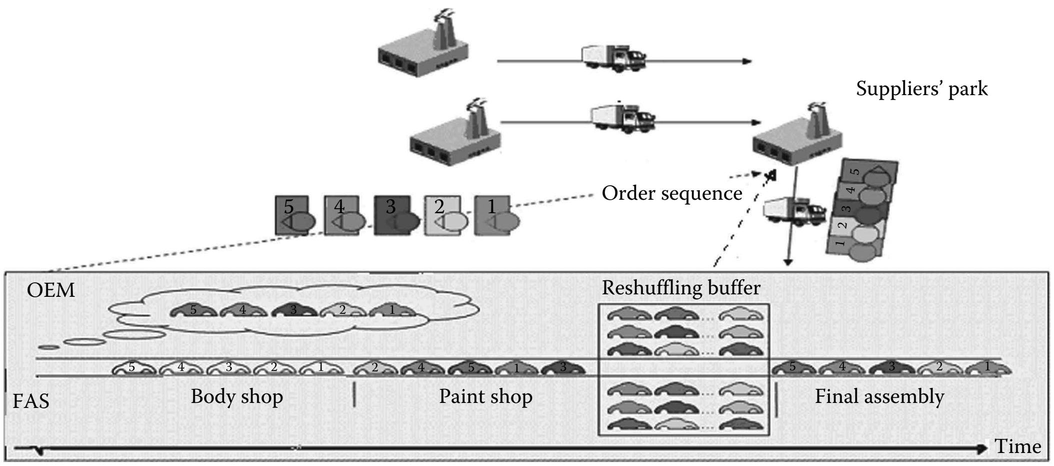

FIG. 50.9
Just-in-sequence deliveries from suppliers' park.

In fact all logistics activities are outsourced. Only strategically important components and operations are executed by BMW (painting, chassis). The LLPs are not only responsible for the in-house logistics and fully integrated with production but they are also part of the BMW quality control. Less important 1-tier suppliers and the 2-tier suppliers are only loosely integrated in the production. The quality of these less integrated suppliers is mainly controlled through the quality standards like ISO or TS. The results of this collaboration are impressive [10]:

- 50% fewer faults per vehicle
- Cost reduction

Level of productivity is 20% higher than in the other BMW plants.

(see 0.5 Tier supplier descriptions above). The suppliers create modular consortia that are responsible for production of a particular automobile module in the time framework synchronized with main assembly operation at the OEM facility.

PRODUCTION CONTROL

Effective production control requires the appropriate mechanisms for process flow monitoring and its normalization when fluctuations appear. The scope of fluctuations in the production flow caused by disturbances very often is bigger than the buffering abilities of the manufacturing system. Simultaneously the traditional methods for production planning and control are not always sufficient in conditions of uncertainty. Insufficient production processes control might cause a crisis that threatens seriously the continuity of operations. The goal of production control in automobile industry is to fulfill customers' orders on time and on also to protect initial sequence of production orders. The main value-adding activities take place at the final assembly department. Due to the application of JIT/JIS delivery schema adopted by most of the manufacturers, compliance with initial production sequence is very important. The model for production planning and control in automobile plant is presented on Figure 50.11.

The planning activities were already discussed in the previous sections so the emphasis will be placed on the control activities. In order to efficiently control the production flow, there is a need for real-time updated data on executed production sequence. The production system in the automobile plant is monitored usually by a number of scanners that register the data from bar codes/GS1 codes plugged to any car body at the beginning of the production process. The places where scanners are located can be called production control points (PCP). The number of PCPs differs among different manufacturers. Data from PCPs are sent in real time to production databases. The structure of the data depends on a particular company. It can be assumed that the minimal requirements for data needed (Table 50.3):

- Production order identification number (POIN)
- PCP identification code
- Date
- Time when particular POIN passes through particular PCP

In the ideal system, the sequence of production orders at manufacturing system entry should be the same, as this

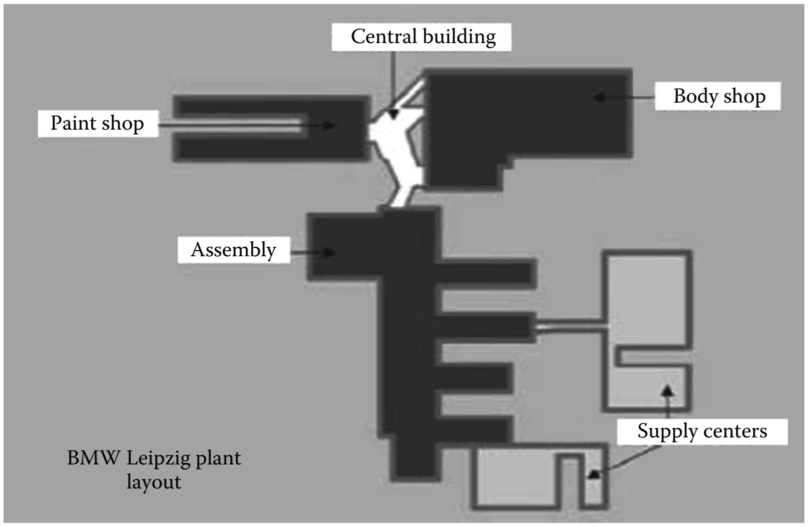

FIG. 50.10

Ground plan of the BMW plant, Leipzig. (From Kochan, A., Assembly Automat., 26(2), 111, 2006.)

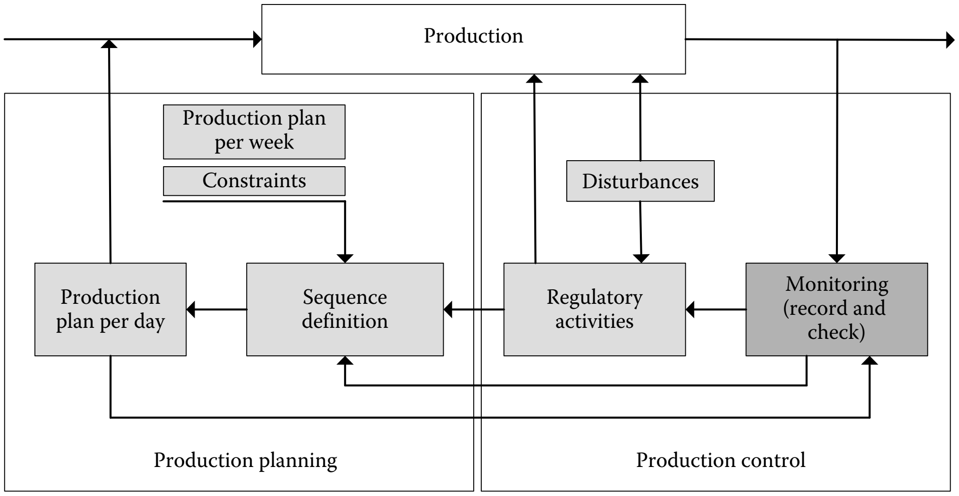

FIG. 50.11
Model for production planning and control.

TABLE 50.3
Simplified Structure of Database

Production Sequence/ PCP	*PCP 1*	*PCP 2*	………	*PCP N*
POIN 1	Date, Time	Date, Time	Date, Time	Date, Time
POIN 2	Date, Time	Date, Time	Date, Time	Date, Time
…	Date, Time	Date, Time	Date, Time	Date, Time
POIN *N*	Date, Time	Date, Time	Date, Time	Date, Time

one observed at the last production control point. In the real manufacturing system, the differences are significant. The sequence at the end of production system compared to the manufacturing system entry is both mixed within a defined block of orders and also inconsistent. This inconsistency is perceived as a fragmentation of original block of items into smaller blocks and its mixture with others blocks. Consequently, it is impossible to forecast precisely both the time when a defined block of order would be manufactured and the order within block in which the following POINs would appear (Figure 50.12) [12].

All corrective actions are usually only temporary. Very often there is no intention to reintroduce the model sequence of cars, so withdrawn vehicles are not put into the right place fitting best initial plans. Lack of any initiative by the employees to maintain the planned sequence and lack of any initiative to eliminate undesired changes in the sequence are the two common problems in production control in automobile plants. Disturbance management is an important part of production control process.

Disturbance in production control can be defined as an unexpected and unplanned event, which causes the deviation between planned MPS and real production flow within the production system. The deviation between initial planned and real production sequence resulting from intentional planner activities (e.g., change of initial order priority) will not be treated as a disturbance. Disturbances in production system can differ greatly: for example, breakdown of machines, serious delay in deliveries, and workers' absence (Figure 50.13).

From production control point, the disturbances can be classified based on two criteria:

1. Source of disturbance:
   a. Disturbances of resources: machines and tooling, workforce
   b. Disturbances of production system inputs: information, materials, energy
2. The effect it has on the production system [13]:
   a. Production control goal disturbances
   b. Production capacity disturbances
   c. Input disturbances
   d. Information flow disturbances

The main goal of production control is the execution of processes according to the planned MPS. The disturbances of production control function are any deviations in the initial MPS execution appearing at independent demand level caused by changes in customer's demand or customer's order due dates.

The production resource disturbances are any variation in the initial MPS execution caused by limited availability of production capacities (machines, tooling, workforce, etc.). The input disturbances are any variations in the initial MPS execution appearing at dependent demand level caused by shortages of raw materials. The input disturbances are any variations in initial MPS execution appearing at dependent

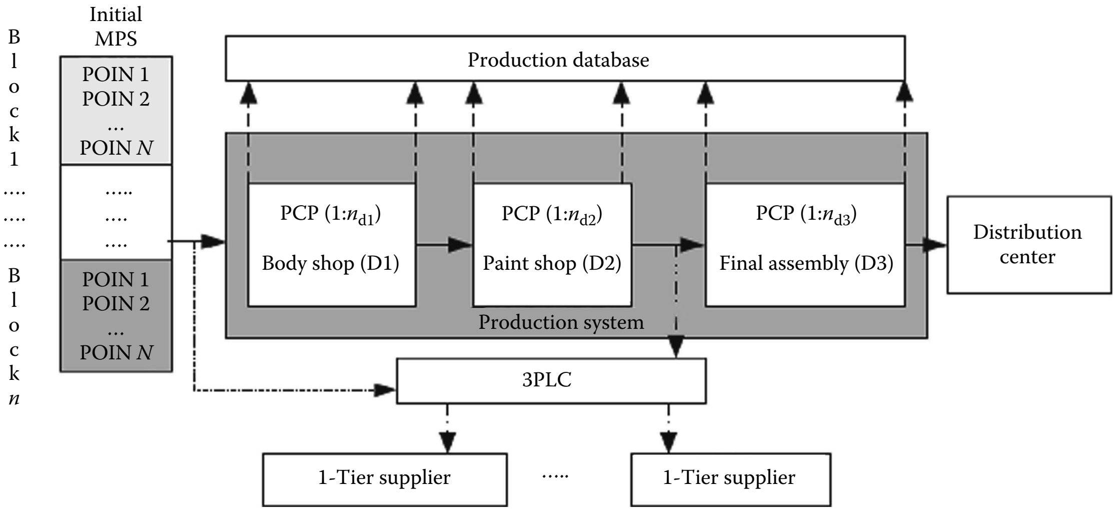

FIG. 50.12

Control process. (From Golinska, P. et al., Production flow control in automotive industry—Quick scan approach, Proceedings of 20 International Conference of Production Research, Shanghai, 2009.)

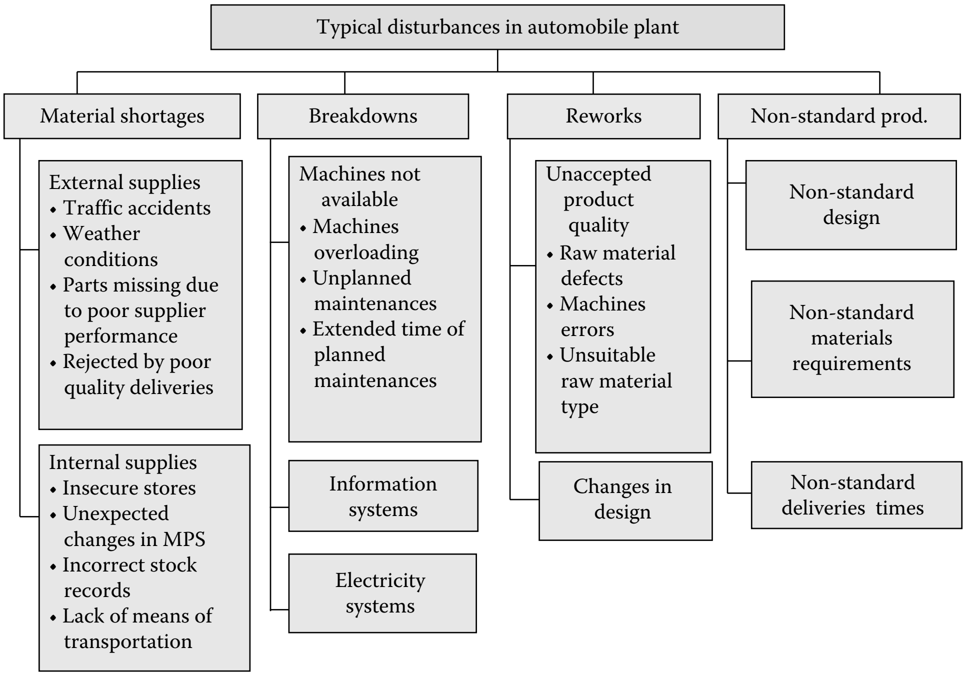
Typical disturbances in automobile plant
Material shortages
Breakdowns
Reworks
Non-standard prod.
External supplies
• Traffic accidents
• Weather conditions
• Parts missing due to poor supplier performance
• Rejected by poor quality deliveries
Internal supplies
• Insecure stores
• Unexpected changes in MPS
• Incorrect stock records
• Lack of means of transportation
Machines not available
• Machines overloading
• Unplanned maintenances
• Extended time of planned maintenances
Information systems
Electricity systems
Unaccepted product quality
• Raw material defects
• Machines errors
• Unsuitable raw material type
Changes in design
Non-standard design
Non-standard materials requirements
Non-standard deliveries times

FIG. 50.13

Typical disturbances in automobile plant.

demand level caused by inappropriate information and data on technology: for example, not updated bill of material, invalid data on maintenances, lead times, and inventory levels.

Production control might be based on the following indicators:

1. Production flow cycle indicator *XY_Long* is counted as a sum of time windows between moments when analyzed POIN passes through following PCPs (Equation 50.1). The time when POIN enters the production system at PCP1 is counted as 0 ($t_{\mathrm{pcp1}}= 0$):

$$XY\_Long = \sum_{i=1}^{n} t_{\mathrm{pcp1}} \qquad \textbf{(50.1)}$$

2. For a block of k number of POINs, the indicator is counted as

$$XYLong\_set_{\mathrm{av}} = \frac{\sum_{1}^{k} \mathrm{POIN}_k \sum_{i=1}^{n} t_{\mathrm{pcp1}}}{k} \qquad \mathbf{(50.2)}$$

   In order to define the typical and critical values of production flow cycle indicator for a block of POINs on the basis of long time observation of nondisturbed POINs (with the same key features as the analyzed block), the "ideal" values are counted: XYLong_setID.

3. Sequence dispersion range (SDR) measured for a block of POIN as a difference between maximum order identification number in defined block and minimum identification number observed at chosen production control point:

$$SDR = (POIN\,\mathrm{max} - POIN\,\mathrm{min}) \qquad \mathbf{(50.3)}$$

   The values of SDR indicators show how defined at MPS block of POINs has been distorted by appearance of number of POINs belonging to the other blocks of orders.

4. The overall production sequence quality presents the number k of POIN in analyzed block to SDR at the observed PCP; for example, if there was "k" POIN and the SDR equals to "k," the quality of operations management regarding sequencing will be 100%. The value of this indicator is counted as follows:

$$OPSQ = \frac{k}{SDR} \times 100\% \qquad \mathbf{(50.4)}$$

The low value of OPQS indicator informs about serious disturbance in production flow for analyzed block. On the basis of proposed indicators, it is possible to monitor production flow and to identify when serious disturbances appear and regulatory activities are needed (Table 50.4).

REVERSE LOGISTICS AND REMANUFACTURING

The automotive industry has adopted a life cycle approach as one of its major focus. This approach is highlighted in fulfillment of following goals:

- Steady improvement in vehicle recovery rates
- Increased use of renewable resources and recycled materials
- Increased utilization of used parts
- Reduction of hazardous substances like lead, mercury, cadmium, and hexavalent chromium
- Reduction of CO_2 emission

Automobile manufacturers are involved in remanufacturing activities of elements such as tires, alternators, and engine elements for many decades. The introduction of EU regulations for this industry like end-of-life vehicles (ELV Directive 2000/53/EC) and directive on type approval of vehicles for reusability, recyclability, and recoverability (RRR 2005/64/EC) has created a need for the new business practices in area of materials management. Growing concerns of sustainability exert a huge pressure on the companies to measure their impact on the environment. Closed loop approach integrates forward and reverse logistics processes. An ideal closed loop supply chain should be zero-waste as it completely reuses, recycles, or composts all materials.

Companies try to include their used products in their logistics operations as an alternative source of materials (resupply). Figure 50.14 presents the closed loop supply chain.

The forward supply chain processes include activities such as purchasing, transportation, and storing of the raw materials and new components ("supply" phase of supply chain). Production/manufacturing enhances all value-adding processes that transform the raw materials and components into final products according to actual customers' demand or demand forecasts. The final stage of forward material flow is distribution that refers to all activities needed to provide the customers with ordered/demanded products. Distribution usually consists of transportation, storage, and sales services. In case of closed loop supply chains, the distribution

TABLE 50.4

Identification of the Type of Disturbances

Effects Caused in Production by Uncertainty	*Fall of OPSQ Indicator under Critical Value*	*Growth of XY Long Indicator over Critical Value*
Production capacities disturbances	Machine breakdown at the separate production process part	Breakdown of information systems, breakdowns of electricity supplies, machines' breakdown at the joint part of the production process
Input disturbances	Nonstandard material requirements. Nonstandard supply lead times, poor quality, lack of needed components	Nonstandard supply lead times, poor quality, lack of needed components
Information flow disturbances	Invalid production data (mainly invalid BOM)	Changes in design of product, nonstandard design

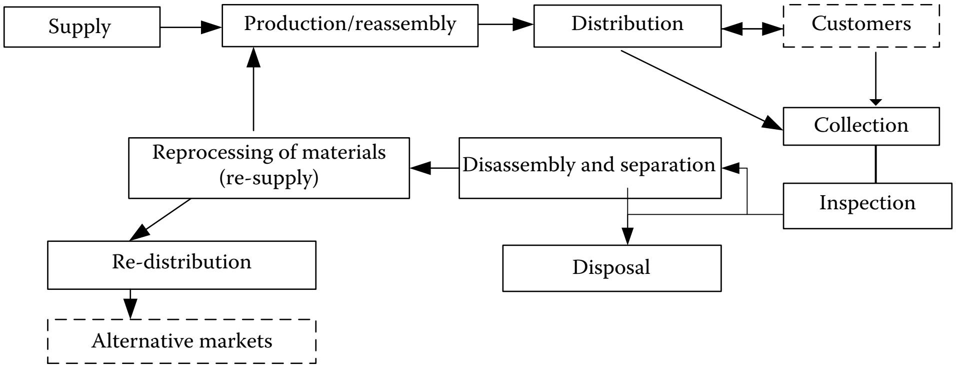

FIG. 50.14

Materials flows in closed loop supply chain. (Modified from Fleischmann, F. et al., Prod. Oper. Manage., 10/2, 156, 2001.)

processes might include the optional collection of end-of-life products from customers. The closed loop approach points out to the importance of efficient reverse flows management in order to reduce the size of waste being disposed. Reverse processes start with all activities rendering used products available and moving them to the place of further treatment. The inspection/separation denotes all operations determining whether a given product is reusable and in which way, and it results in splitting the flow of used products according to distinct reuse (and disposal) options [14]. Reprocessing may take different forms including

- Recycling
- Reuse/rebuilt/repair
- Remanufacture

Redistribution includes all activities needed to directing delivery of reusable products to a potential market. The sustainable supply chain management requires continuous course of actions in order to decrease the environment impact of products and technology used by manufacturer and this prechain (suppliers) and postchain (collection, inspection, and reprocessing activities).

Remanufacturing can be defined as an industrial process in which a new product is reassembled from an old one and, where necessary, new parts are used to produce fully equivalent and sometimes superior-in-performance and expected lifetime original new product [15]. Remanufacturing is distinctly different from repair operations, since products are disassembled completely and all parts are returned to like-new conditions, which may include cosmetic operations [16]. Remanufacturing of automotive parts is very similar to assembling of new parts, except that many of the components are taken from used parts so the part must be completely disassembled, cleaned, and examined. Worn out components are replaced with new or rebuilt components [17]. Electrical parts frequently need rewinding or rewiring. The remanufactured part must be tested for compliance with technical specifications. The biggest advantage for customer is that remanufactured part normally costs 50%–75% of the cost of a comparable new one [25]. Remanufacturers provide customers with warranty. Remanufacturing allows companies to capture the residual value added in forms of materials, energy, and labor. Remanufacturing is the most advanced form of reprocessing operations, but in case of end-of-life products or almost at this stage, sometimes it is not appropriate. The reason is the cost and complexity of remanufacturing operations. Lund [15] has identified seven criteria for profitable remanufacturability:

1. Product is a durable good.
2. Product fails functionally.
3. Product is standardized and the parts are interchangeable.
4. Remaining value added is high.
5. Cost to obtain product is low compared to the remaining value.
6. Product technology is stable.
7. Costumer is aware that remanufactured goods are available.

Recycling activities require the destruction of the product to its components and materials so they can be melted, smelted, or reprocessed into new forms (www.remanufacturing.org.uk). Recycling is putting used materials back into the manufacturing chain at a very basic level. According to a definition, “Very simple, low-cost products, broken goods beyond redemption, rapidly evolving designs, and even the bits that have to be replaced during remanufacture and reuse are good candidates for recycling” [26]. The output of recycling process could be the same products, when the quality is good enough (e.g., steel, automotive plastics) or new ones in cases where used materials are not meeting the quality standards.

Reuse can be divided into

- Straight reuse by other user with lower quality expectations (less developed markets)
- Refurbishment—cleaning, lubricating, or other improvements
- Repair/rebuilt

- Redeployment and cannibalization—using working parts elsewhere

Rebuilt operations are applied for automotive industry mainly for heavy duty equipment such as bus and truck fleets, farming equipment, and construction equipment when new parts many be difficult or impossible to obtain.

End-of-life vehicle (ELV) directive requires manufacturers to reach the goal of new vehicles reusability and/or recyclability of at least 85%, and reusability and/or recoverability of at least 95% by weight, if measured against the international standard ISO 22620 [26]. From these ELVs, dismantling companies first remove the oils, engines, transmissions, tires, batteries, catalytic converters, and other parts, which are then recycled or reused. Shredding companies then sort out the ferrous and nonferrous metals, resins, and other materials. While the ferrous and nonferrous metals are recycled, the remaining material is collected by automobile manufacturers and recycled/recovered or processed appropriately.

The reusability, recyclability, and recoverability (RRR) directive 2005/64/EC on type approval of vehicles came into force in December 2005 and requires cars and light vans (M1/N1), newly introduced to the market after December 2008, to be 85% reusable and/or recyclable and 95% reusable/recoverable by mass. Focus on recyclability has driven the new model planning process. Newly applied advanced recycling methods (e.g., postshredder treatment) allow nowadays the recycling and recovery of literally all materials. However, it should be noted that life cycle assessment showed limited environmental impact of mechanical recycling for nonmetals. Moreover, shift in design approach, the so-called product modularity, allows improving disassembly operations [18]; the vehicle electronics are also designed so that all pyrotechnic devices (airbags, etc.) can be neutralized safely and simply by operatives using a common interface (ISO 26021). For vehicles already on the market, there are vehicle-specific adapters available to enable the dismantlers safely to deploy all pyrotechnic devices [28]. Components that contain fluids are positioned so that they can be accessed quickly and gravity is applied for the preliminary depollution process. To speed up the dismantling operations all components are labeled in accordance with international ISO standards, enabling materials to be sorted according to type. In order to reach the challenging goal of 95% recovery target by 2015, some efficient material separation technologies for ELVs are promoted that allow the utilization for shredder residue and boosting the usage of recycled materials for some specific car components.

At the end of 2007 in Europe, there was altogether over 224 million passenger cars in use [26], including 68 millions older than 10 years. The average age of car in the old EU 16 countries was 9.7 years, including the rest of European countries, it increased to over 11 years. The problem of old vehicles is growing.

However, in the United States, as there is no formal law requirement like ELV, auto makers support the principle of extended producer responsibility (EPR) [19] and their role in helping consumers to recycle ELVs. The United States is the largest market in the world (over 28% of total number of vehicle used). In the U.S. market, 15 million cars are estimated to reach end-of-life state [20]. On average, U.S. manufacturers reach the goal of 75% material recoverability and recycling ability. In the last decade, a number of sustainable practice was introduced, for example, in Ford

- Issues recycling guidelines to the suppliers
- Uses recycled tires and household carpeting in car production

In Japan, ELV regulation was introduced in 2005. According to the law, requirements the recycling process are organized in four steps:

1. All the liquids and internal equipment as well as tires are removed and recycled.
2. Car body is compressed and shipped to pointed facility.
3. The compressed body is sent to a shredder and divided into steel and nonsteel materials: automobile shredder residue (ASR).
4. Other materials: ASR are dumped into the sea to create an artificial island.

The Japan Automotive manufacturers are obliged to reach the goal of recycling rate by over 95% until 2015. RRR is high among all Japan automotive manufacturers in Toyota. It has introduced innovative method of disassembly, which allows to lower cost and time required for this operation. Toyota points the dismantle points in their vehicles and the attached dismantle manual (Figure 50.15). This practice allows lowering the time required by 45% for disassembly operations [29]. Also Nissan has introduced some innovative thermal recycling process for ASR reduction.

From economical and environmental points of view, the most promising form of reprocessing is remanufacturing. The automobile industry has the longest tradition in remanufacturing among all industries. According to Steinhilper [17], the automobile product remanufacturing accounts for two-thirds of all remanufacturing and is a $53 billion industry in the United States alone and at least $100 billion industry throughout the world. Ten percent of all cars and trucks require an engine replacement during their lifetime. About €120 million worth of remanufactured products were sold in 2005 worldwide [21]. Starters and alternators are the most typical products to be remanufactured due to the fact that most cars require two of each throughout their lives, and these two components are mass produced and remanufactured by thousands of companies. Alternator and starter motors are ideal candidates for a profitable remanufacturing, as these components have very high production volumes and low un-manufacturability [22]. About 300 starter motor and alternator remanufacturers are

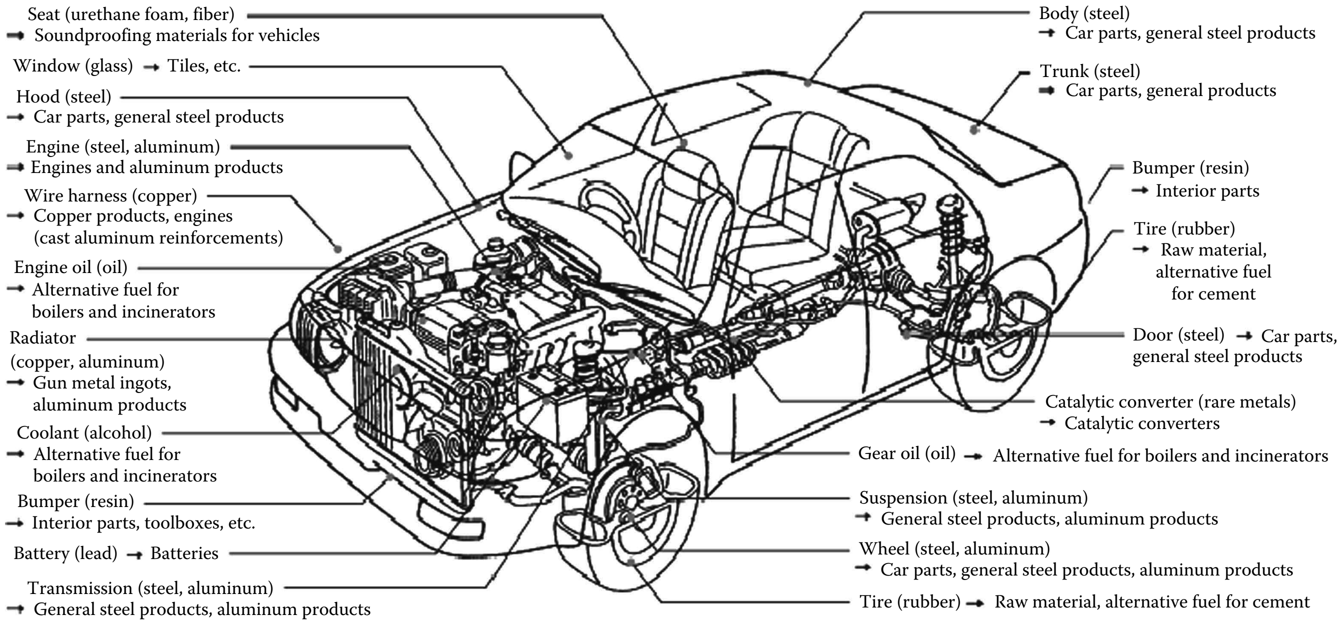
Seat (urethane foam, fiber)
→ Soundproofing materials for vehicles
Window (glass) → Tiles, etc.
Hood (steel)
→ Car parts, general steel products
Engine (steel, aluminum)
→ Engines and aluminum products
Wire harness (copper)
→ Copper products, engines
(cast aluminum reinforcements)
Engine oil (oil)
→ Alternative fuel for
boilers and incinerators
Radiator
(copper, aluminum)
→ Gun metal ingots,
aluminum products
Coolant (alcohol)
→ Alternative fuel for
boilers and incinerators
Bumper (resin)
→ Interior parts, toolboxes, etc.
Battery (lead) → Batteries
Transmission (steel, aluminum)
→ General steel products, aluminum products
Body (steel)
→ Car parts, general steel products
Trunk (steel)
→ Car parts, general products
Bumper (resin)
→ Interior parts
Tire (rubber)
→ Raw material,
alternative fuel
for cement
Door (steel) → Car parts,
general steel products
Catalytic converter (rare metals)
→ Catalytic converters
Gear oil (oil) → Alternative fuel for boilers and incinerators
Suspension (steel, aluminum)
→ General steel products, aluminum products
Wheel (steel, aluminum)
→ Car parts, general steel products, aluminum products
Tire (rubber) → Raw material, alternative fuel for cement

FIG. 50.15

Examples of car parts that can be recycled. (From www.toyota.co.jp)

active worldwide. Fifty percent of the companies are U.S. producers; the other 30% of the companies are located in Europe. Their production volumes together are about 50 million pieces, which constitutes more than 80% of the overall remanufactured products [21].

Studies have been performed that conclude the following (www.apra.org):

- About 50% of the original starter is recovered in the remanufacturing process. This can result in annual savings of 8.2 million gallons of crude oil from steel manufacturing, 51,500 tons of iron ore, and 6,000 tons of copper and other metals in the United States.
- Rebuilt engines require 50% of the energy and 67% of the labor that is required to produce new engines.

Studies [17] by the Fraunhofer Institute in Stuggart, Germany, demonstrated the following:

- The yearly energy savings by remanufacturing worldwide equals the electricity generated by five nuclear power plants or 10,774,000 barrels of crude oil, which corresponds to a fleet of 233 oil tankers.
- The yearly raw materials saved by remanufacturing worldwide would fill 155,000 railroad cars forming a train 11,100 miles long.

Remanufactured products conserve not only the raw material contents but also much of the value added during processes required to manufacture new products [23]. Remanufacturing profitability can be driven by the reverse flow of materials and makes companies optimize their reverse channels.

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